

USE OF DIESEL MIXED WITH ETHANOL AND ETHYL ACETATE FOR ALTERNATIVE FUEL IN A HIGH-SPEED DIESEL ENGINE

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Abstract

Particulate matters especially particles with less than 2.5 micrometers (PM_{2.5}) are the main cause of severe air pollution problem in Thailand that lead to the mortality risk in cardiovascular disease. Exhaust gas emissions specifically carbon monoxide and black smoke from diesel engines are the essential sources in generating significant amounts of PM_{2.5}. Improving diesel properties by mixing oxygenated additives is one of the alternatives in reducing this pollutant. The main objective of this research is to investigate the performance and emission of a high-speed diesel engine at 3,000 rpm and different loads operated with diesel mixed with 5 to 20% ethanol and 5% ethyl acetate. The results of engine test at 80% load using diesel mixed with 5% of ethanol and ethyl acetate showed a few decreases in fuel properties and engine performance compared with diesel. The release of black smoke was also decreased to 14%. Increasing the mixture of ethanol to more than 5% has led to the decrease in engine performance continuously. The diesel mixed with ethanol at 20% and ethyl acetate at 5% has reduced the carbon monoxide and black smoke to 0.012% vol and 31.53% respectively and accrued the carbon dioxide at 1.25% vol. This is because the diesel mixed with ethanol and ethyl acetate increased the oxygen level to perform complete combustion as compared with diesel. However, the temperature of these exhaust gases was raised to 55°C.

Keywords: Diesel engine, Emissions, Ethanol, Ethyl acetate, Performance

Introduction

Renewable energy became an essential key to decrease the environmental concerns and driving the economy in the ASEAN region. One of the factors for driving the agricultural and transportation sector in Thailand is the wide range use of diesel such as low-speed diesel engines in mechanical agricultures and water pumps or high-speed diesel engines in generators and vehicles. However, the use of diesel engines also continuously release the innumerable

particulate matter particularly with less than 2.5 microns (PM_{2.5}) such as black smoke that lead to human health issue in the country. Several studies dedicated in curbing the diesel-engine emissions shown that methods such as emulsification, fumigation, and modification could reduce the black smoke level [1, 2].

Mixing diesel with oxygenated additives by emulsification is considered as one of the best methods in decreasing the engine pollutants because it does not require engine modification and it is relatively low cost [3, 4]. Some researchers [5, 6] found that mixing diesel with ether acetates such as 2-ethoxyethyl acetate and 2-methoxyethyl acetate resulted in the improve of engine performance and curbing the exhaust gas emissions. Other researchers [7, 8] also found that mixing diesel with alcohols such as n-propanol and n-butanol resulted in an increase in thermal efficiency and changing in the black smoke release. However, some oxygenates as fuel additives are expensive, toxic and low homogeneity. Ethanol is currently an attractive alternative fuel in Thailand because it could be produced from agricultural crops and it is less toxic and not carcinogenic. In addition, oxygen (O₂) content within diesel mixed with ethanol could also decrease the diesel-engine emissions [2, 3]. However, increasing ethanol into diesel will also increase the stratification time that causes the build-up in engine knock [2, 4, 9]. Some researchers [1, 2] suggested that adding emulsifier or solvent in diesel mixed with ethanol could improve fuel stability leading to the improve in engine performance and reduction in engine emissions.

Several researches [10-14] found that using diesel mixed with biodiesel and increased ethanol also resulted in gas emissions drop though it decreased the fuel properties especially viscosity and calorific value. It is noted from the previous research [10] that the optimal diesel-biodiesel-ethanol (D-B-E) mix was at 78% diesel, 17% biodiesel and 5% ethanol which resulted in lower emissions as compared to diesel. It is also noted from other researches [2, 12] that increasing ethanol had to be appropriate to the amount of biodiesel in the D-B-E mix. Research [9] found that acetaldehyde of lower than 5% could be used as alternative solvent in diesel mixed with ethanol and other researches [3, 4, 15, 16] has studied the mixtures of diesel, ethyl acetate, and ethanol by adding ethyl acetate for more than 5%. These researches concluded that the use of 5% ethyl acetate in the diesel mixed with ethanol could increase the fuel stability more than two months while the fuel properties were still similar to diesel. Research [17] also concluded that adding 5% n-butanol into 85% diesel mixed to 10% ethanol resulted in the best fuel stability due to almost unseen stratification.

The previous studies as highlighted above were mostly focused on the emulsifiers such as ethyl acetate, n-butanol, biodiesel, etc. It is noted that the ethanol used in the previous studies was anhydrous and hydrous ethanol mixed from between 5 to 20% because the mixing of more than 20% resulted in the quick reduction of homogeneity between ethanol and diesel [3, 4]. It is also noted that the use of diesel mixed with hydrous ethanol (up to 95%) and solvents (up to 2%) led to the dramatic reduction of engine performance and the increased in engine vibration. Contrarily, the use of diesel mixed with anhydrous ethanol (up to 99.9%) and emulsifiers (up to 2%) resulted in the engine performance closed to diesel while reducing various emissions especially carbon monoxide (CO) and black smoke [1, 2]. Moreover, the adding of solvents (up to 5%) led to the almost unseen stratification, the addition of engine performance, and the

reduction of CO and black smoke releases [3, 4, 17]. The critical key for improving the quality of diesel mixed with anhydrous ethanol is the addition of emulsifier up to 5%. However, some solvents such as n-butanol, acetaldehyde and biodiesel are expensive and difficult to produce while other solvent such as ethyl acetate could be produced as emulsifier from ethanol and it is relatively cheap [3, 4]. The studies of diesel mixed with ethanol by using ethyl-acetate emulsifiers are still few and mainly tested with a low-speed diesel engine in the agricultural sector [1, 2, 13, 15]. Therefore, the main objective of this research is to investigate the performance and emission characteristics of a high-speed diesel engine at 3,000 rpm and different loads operated with diesel mixed with 5 to 20% ethanol and 5% ethyl acetate.

Methodology

Preparation of Diesel Mixed with Ethanol and Ethyl-Acetate Emulsifiers

Substances using in the emulsification consist of diesel, anhydrous ethanol (99.9%w) and ethyl acetate (99.6%w). The properties of these substances such as fuel density, kinematic viscosity, flash point temperature, and lower heating value (LHV) are shown in Table 1.

Table 1. Fuel Properties

Items	Density (kg/m ³)	Viscosity (cst)	Flash Point (°C)	LHV (MJ/kg)
ASTM	D1298	D445	D93	D240
Diesel	831	2.2	71.80	44.12
Anhydrous ethanol	790	1.40	174.00	26.33
Ethyl acetate	881	0.41	81.00	22.80
DE5Ea5	819	1.82	13.40	43.13
DE10Ea5	810	1.74	11.60	42.86
DE15Ea5	804	1.63	8.20	41.70
DE20Ea5	799	1.53	6.80	40.48

The proportions of diesel, ethanol, and ethyl acetate (DEEa) in different mixtures comprises of diesel (D) at 90, 85, 80, and 75%v mixed with ethanol (E) at 5, 10, 15, and 20%v and ethyl acetate (Ea) at 5%v to produce DE5Ea5, DE10Ea5, DE15Ea5, and DE20Ea5 respectively. In the emulsion process, the DEEa mixtures were stirred at 800 rpm in a round bottom glass connected with the electromagnetic machine and the mechanical stirrer and the mixing temperature was fixed at 30 °C referred to phase diagram of Research [1]. Fuel properties of DEEa under various ASTM procedures is lower than diesel as shown in Table 1. Fuel density decreased between 1.44 to 3.86%, kinematic viscosity decreased between 19.97 to 32.70%, flash point temperature decreased between 58.4 to 65 °C, and LHV decreased between 2.26 to 8.25%. These results are similar to Research [18] and the LHV is higher than Research [16] under the

same conditions. The diesel mixed with 5% ethanol and ethyl acetate (DE5Ea5) has the same fuel properties as compared to researches [3, 4, 10] which could be applied as an alternative fuel for diesel engines in the future because some of the fuel properties particularly viscosity and density are also within the specifications of regular diesel standard by the Department of Energy Business, Thailand.

Experimental Setup

Performance and emissions test of the high-speed diesel engine were investigated at the automotive biofuels and combustion engineering research laboratory in Burapha University. The schematic of the experimental setup is shown in Figure 1 and the specification of the high-speed diesel engine is shown in Table 2.

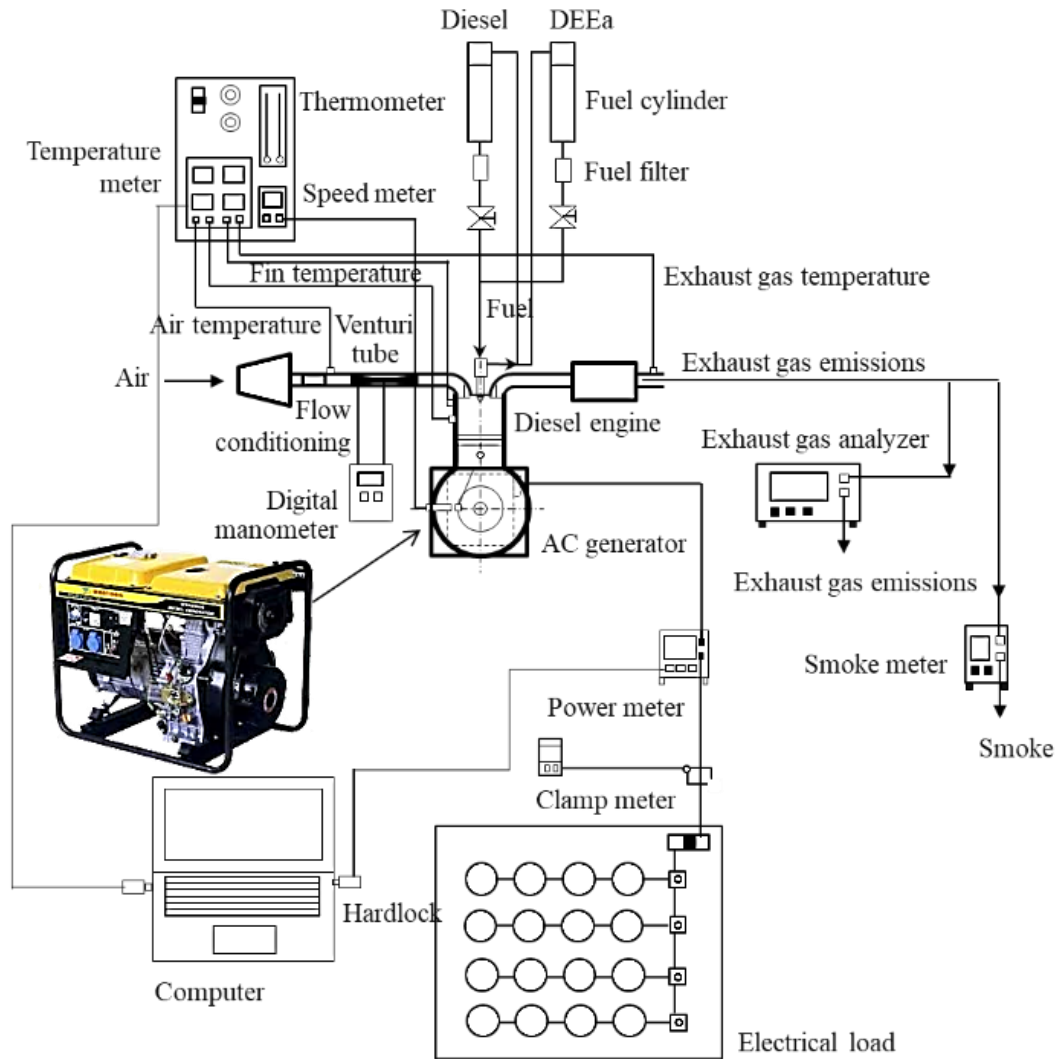


Figure 1. Schematic of experimental setup

Table 2. Specification of the High-speed Diesel Engine

Item	Description
Engine model	Mitsuki: MIT-186FG
Engine classification	Naturally-aspirated, air-cooled, DI system
Cylinder number	1
Displacement (cm ³)	406
Bore x Stroke (mm)	86x70
Compression ratio	18:1
Maximum power (kW) / speed (rpm)	8.5 / 3,000

The engine used in this research was the direct injection (DI) diesel engine connected with the 5 kWe generator and operated at 3,000 rpm. This research used various electric lamps to increase the engine loads that was analyzed using a power meter richtmass RP-96EN with the clamp IMARI-CT100/1A. The data was recorded from richtmass RS485 using a USB data converter and hardlock for the RP series connected with a computer. The calibration was made for power-meter parameters with a clamp meter. The K-type thermocouple was applied with a temperature meter for measuring the fluid temperatures such as coolant, intake, exhaust gas, etc. A fuel cylinder was used to record the fuel flow rate for calculating the fuel consumption rate. Finally, the levels of exhaust gas emissions especially carbon dioxide (CO₂) and carbon monoxide (CO) were measured using the Cosber: KWQ-5 Automotive emission analyzer with a non-dispersed infrared (NDIR) method. The quantity of the black-smoke was measured using the Cosber: KYD-6 Opacimeter with light-absorption (m-1) method then changed to the common unit of g/kWh as per Reference [19]. The basic characteristics of the exhaust gas emissions and black smoke are shown in Table 3.

Table 3. Range and Accuracy of Exhaust Gas Measurements

Measurements	Methods	Range	Accuracy
CO ₂ (% vol)	NDIR method	0-18	±0.02
CO (% vol)	NDIR method	0-15	±0.02
Black smoke (m ⁻¹)	Light-absorption	0-16	±0.05

Experimental Procedure

The diesel engine was warmed up about 15 minutes until stable and the air intake manifold and air surrounding temperatures as controlled at 30±3 °C. The experiments started by using diesel and diesel mixed with ethanol (adding from 5 to 20%) and ethyl acetate at 5% (DE5Ea5, DE10Ea5, DE15Ea5, and DE20Ea5) respectively. The engine speed was controlled at 3,000 rpm and the measurement error was set at ±50 rpm. After the diesel engine was stable at the air-cooled temperature, the electrical load was increased from 20 to 100%. The fuel volume was fixed at 20 ml to calculate the mass and volume flow rate. The performance parameters such as fuel flow rate, speed, electrical power, temperatures, and release of CO₂, CO, and black smoke

were analyzed especially for thermal efficiency, specific fuel consumption and engine emissions as compared with diesel. The overall periods of the engine tests were between 50 to 100 hours and the tests were repeated at least 3 times for each condition as per References [3, 4].

Results and Discussion

Results of engine performance and emission test by using the DEEa mixtures as compared with diesel at speed 3,000 rpm and different loads are described below.

Electrical Power

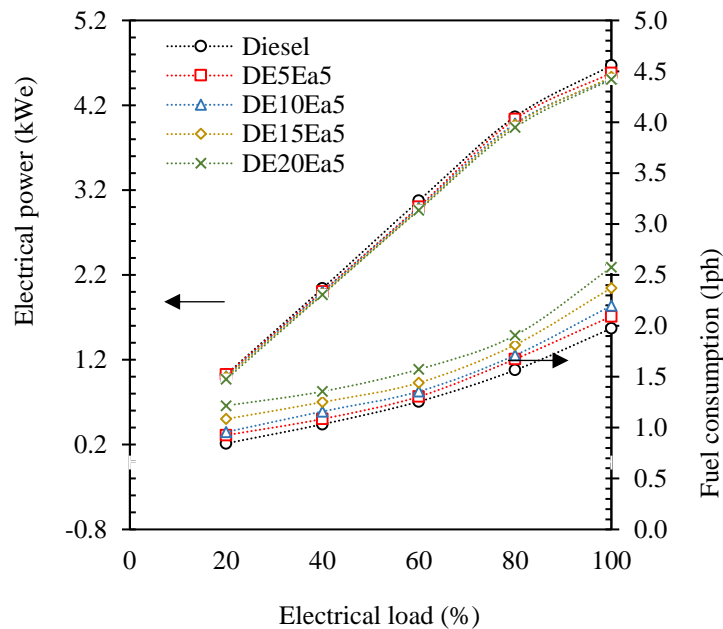


Figure 2. Electrical power and fuel consumption at different loads

Figure 2 (left side) showed that the electrical power increased with the increased of electrical loads. Diesel mixed with 5% ethanol and ethyl acetate (DE5Ea5) had closer electrical power to diesel. Diesel mixed with 10 to 20% ethanol and ethyl acetate of 5% (DE10Ea5, DE15Ea5, and DE20Ea5) had lower electrical power than diesel between 3.1 to 3.6. These results are similar to Researches [2, 13, 19, 20]. The alcohols (ethanol and ethyl acetate) concentration could increase the latent heat of vaporization and promote the ignition delay and so the engine power decreased because the fuel mixtures could not be burned completely. The decrease in engine power could also be caused by the decrease of LHV of diesel mixing with alcohol. The diesel mixed with ethanol and ethyl acetate of more than 10% in the high-speed diesel engine resulted in the reduction of electrical power to 4% at full load.

Fuel Consumption

Figure 2 (right side) showed that fuel consumption increased with the increased in electrical loads. The diesel mixed with ethanol (adding from 5 to 20%) and ethyl acetate at 5% had higher fuel consumption than diesel between 5.97 to 30.67% at full load. These results are similar to

Researches [1-4]. The higher fuel consumption could be due to the lower caloric value and the increase in fuel flow rate. However, the use of DE5Ea5 in the high-speed diesel engine showed that the maximum fuel consumption was not more than 7% as compared with diesel at each load.

Thermal Efficiency

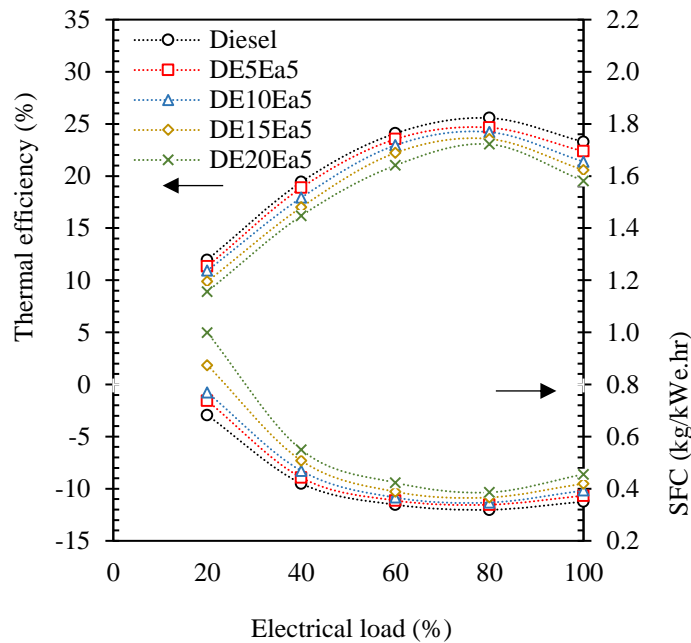


Figure 3. Thermal efficiency and SFC at different loads

Figure 3 (left side) showed that thermal efficiency increased with the increased in electrical loads with the best thermal efficiency occurred at 80% load. The use of diesel mixed with ethanol (adding from 5 to 20%) and ethyl acetate at 5% showed the increase in thermal efficiency at 80% load between 0.92 to 2.51%. These results are similar with Researches [1-4]. The increase in thermal efficiency could be due to the lower calorific value that resulted in higher fuel consumption and increased in the input energy. Since diesel mixed ethanol has higher input energy then their thermal efficiency will further decrease with the increase in ethanol. However, the use of DE5Ea5 in the high-speed diesel engine showed that the reduction of thermal efficiency was not more than 1% as compared with diesel.

Specific Fuel Consumption

Figure 3 (right side) showed that specific fuel consumption (SFC) decreased with the increased in electrical loads with the best SFC occurred at 80% load. The use of diesel mixed with ethanol (adding from 5 to 20%) and ethyl acetate at 5% showed the decrease in SFC at 80% load between 6.10 to 21.88%. The overall SFC of diesel mixed ethanol is higher than diesel that are similar with the Researches [1-4]. However, the use of DE5Ea5 in the high-speed diesel engine showed that the increased in SFC was not more than 10% as compared with diesel in each load. Therefore, DE5Ea5 could potentially replace diesel in the future because the engine performance would only be slightly reduced.

Exhaust Gas Temperature

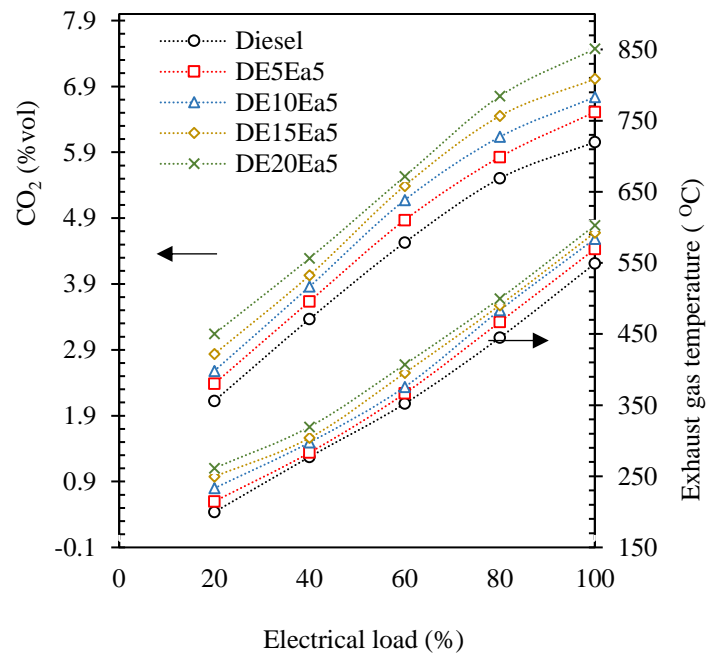


Figure 4. Exhaust gas temperature and CO₂ release at different loads

Figure 4 (right side) showed that the exhaust gas temperature (EGT) increased with the increased in electrical loads. The use of diesel mixed with ethanol (adding from 5 to 20%) and ethyl acetate at 5% resulted in the level of EGT rising from 22 to 55°C as compared with diesel at 80% load. These results are different with Researches [3, 4] but similar with Researches [21, 22] which is common for the case of diesel application in Thailand. The later researches [21,22] found that diesel mixed with 5% biodiesel resulted in the burning rate within the premixed combustion phase because of the increase of O₂ content within biodiesel. In addition, biodiesel and ethyl acetate have lower molar enthalpy of vaporization and so they could increase the combustion reaction in the diffusion combustion phase. As a result, the burning rate could occur continuously throughout the power stroke leading to the raising of EGT. However, the use of DE5Ea5 in the high-speed diesel engine showed that the increase in EGT was not more than 22°C as compared with diesel in each load. Increasing ethanol to 20% led to the highest level of EGT to 60°C.

Carbon Dioxide

Figure 4 (left side) showed that the release of carbon dioxide (CO₂) increased with the increased in electrical loads. The use of diesel mixed with ethanol (adding from 5 to 20%) and ethyl acetate at 5% showed the level of CO₂ accrued between 0.32 to 1.25% vol at 80% load. These results are different with Researches [3, 4] which is related with EGT as explained earlier. The increase of EGT might also lead to the increase of CO₂ level. In addition, the formation of CO₂ is also related with the complete combustion reaction in the engine cylinder between carbon (C) content from the fuel and O₂ element from the air. Therefore, the biodiesel, ethyl acetate and ethanol of 20% with more O₂ content will lead to the more complete combustion that result in the increase of CO₂ release [1, 2]. However, the use of DE5Ea5 in the high-speed diesel engine showed that the release of CO₂ was not more than 0.5% vol as compared with diesel in each load.

Carbon Monoxide

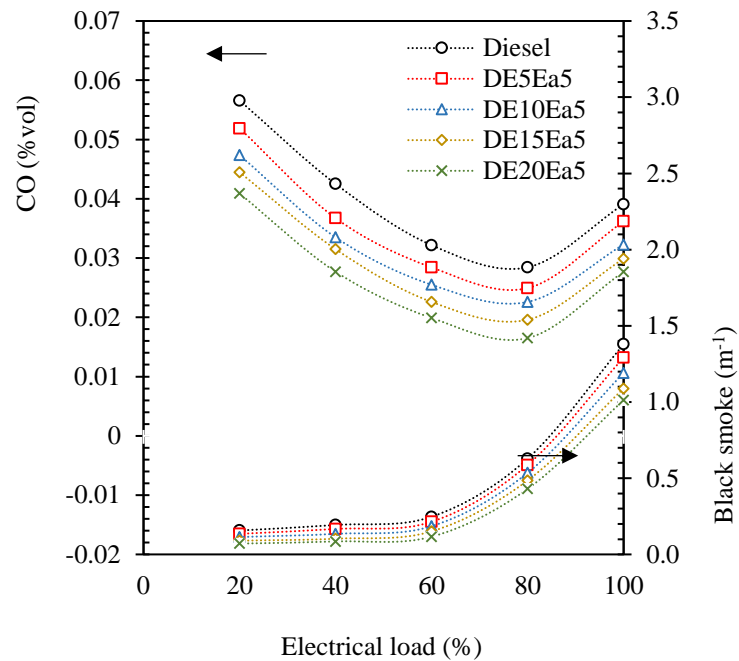


Figure 5. Release of CO and black smoke at different loads

Figure 5 (left side) showed that the release of carbon monoxide (CO) decreased with the increased in electrical loads until 80% load which is consistent with the thermal efficiency trend. The level of CO increased at 100% load due to the changes in the air-fuel ratio at a constant speed of 3,000 rpm. As a result, the combustion of fuel-rich mixture was increased and more CO was released [22]. The use of diesel mixed with ethanol (adding from 5 to 20%) and ethyl acetate at 5% showed that the release of CO accrued between 0.003 to 0.012% vol as compared with diesel at 80% load. These results are consistent with Researches [1-4]. The reduction of CO level is also consistent with the level of CO₂ release as discussed in the earlier section. The use of DE5Ea5 in the high-speed diesel engine showed that the reduction of CO emission was not more than 0.006% vol.

Black-smoke Release

Figure 5 (right side) showed that the black-smoke release increased with the increased in electrical loads especially after 60% load. The increase in electrical load from 80 to 100% led to the increase in fuel flow rate but slight changes in the air flow rate. The amount of air mainly reacted with the vapor fuel in the premixed combustion phase leading to the reduction of air reacting with liquid fuel in the diffusion combustion phase. As a result, there was late combustion that resulted in the increase of the black-smoke level [22].

The use of diesel mixed with ethanol (adding from 5 to 20%) and ethyl acetate at 5% led to lesser black-smoke intensity between 0.041 to 0.198 m⁻¹ as compared with diesel at 80% load. The use of these fuel mixtures also resulted in lesser black smoke level between 6.53 to 31.53% as compared with diesel. These results are consistent with Researches [1, 2] that the

addition of O₂ element in the mixture of ethanol up to 20% and ethyl acetate could lead to more complete combustion within the premixed combustion phase and the increase of the evaporation rate of the remaining oils in the diffusion combustion phase. As a result, the black-smoke intensity is decreased and so the release of black-smoke from engine exhaust pipe is also less. The use of DE5Ea5 in the high-speed diesel engine showed that the reduction of black-smoke release was not more than 14%.

Conclusions

- The use of DEEa mixtures in the high-speed diesel engine has different engine-performance parameters as compared with diesel. DE20Ea5 resulted in the decrease of thermal efficiency to 2.51% and the addition of SFC to 21.88% as compared with diesel. DE5Ea5 is considered as alternative to diesel because it has electrical power similar to diesel and resulted in the decrease of thermal efficiency by 0.92% and addition of SFC by 6.10%.
- The use DEEa mixtures in the high-speed diesel engine also showed different exhaust gas parameters as compared with diesel. DE5Ea5 resulted in the decrease of CO and black smoke release to 0.003% vol and 6.53% respectively but the exhaust gas temperature and CO₂ accrued at 22 °C and 0.32% vol respectively. DE20Ea5 resulted in more decrease in the release of CO and black smoke to 0.012% vol and 31.53% respectively but the exhaust gas temperature and CO₂ accrued to 55 °C and 1.25% vol respectively.
- The present system could be further improved by considering the following suggestions:
 - i. To further investigate the combustion characteristics of the high-speed diesel engine using diesel mixed with ethanol up to 20% and ethyl-acetate emulsifier;
 - ii. To investigate the long-term performance of high-speed diesel engine using DE5Ea5 as the alternative fuel;
 - iii. To investigate the performance and emission of the high-speed diesel engine such as CO, HC, and black smoke using the alternative fuel with other emulsifiers.

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